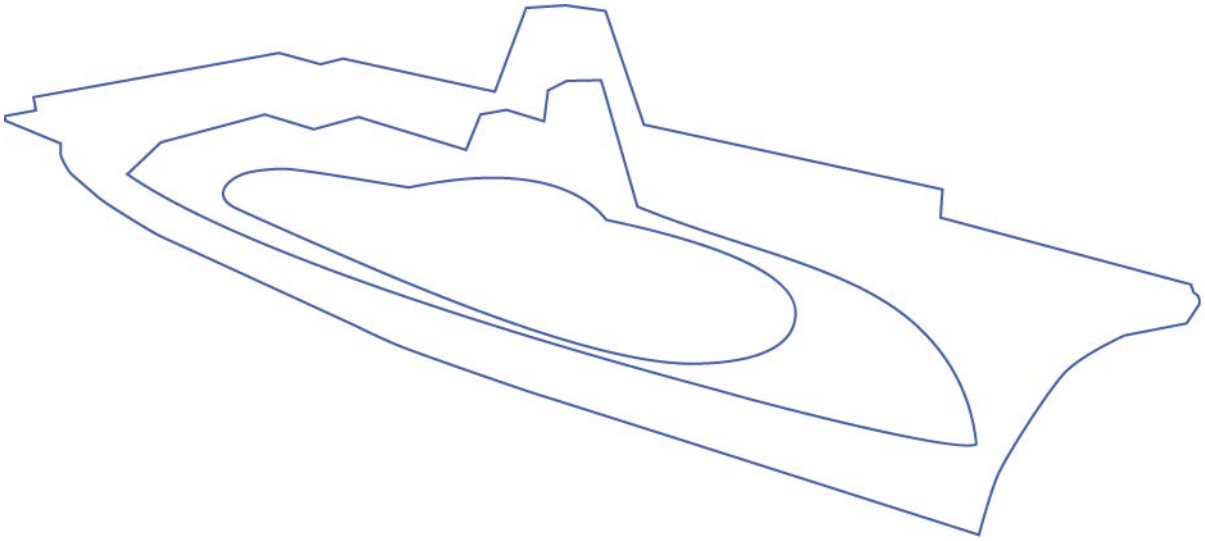
ROADMAP TO AN ELECTRIC NAVAL FORCE



"The Navy is committed to fielding electric powered warships."

CNO Executive Board

2 March 2001

Terms of Reference

For an Electric Naval Force

- **Review and assess recent trends and developments** in the application of electric power to naval platforms as well as weapons and auxiliary systems.

- **Recommend a power system architecture** for optimum long-term exploitation of the benefits of integrated power systems for Naval forces.

- **Recommend a science and technology roadmap** for the development of an integrated electric Naval force and identify possible roadblocks to its successful realization.

Panel Membership

Chairperson

Prof. William F. Weldon (Ret.)

Vice Chairperson

Mr. Peter A. Gale	J J. McMullen Associates, Inc.
Mr. R. Michael Adair	GD Bath Iron Works
Mr. Mark Adamiak	GE Power Management
Mr. Clifford L. Allen, P.E.	Ingalls Shipbuilding, Inc.
Dr. Robert W. Ashton	Naval Postgraduate School
Mr. Charles H. Brown, Jr.	SYNTEK Technologies Corporation
RADM Lewis A. Felton, USN (Ret.)	
Dr. Robert Fischl	F&H Applied Science Associates, Inc.
Mr. John H. Gully	Science Applications International Corporation
Dr. Eric Horvitz	**Microsoft Research**
Dr. James E. Hubbard, Jr.	IproVica
VADM E.R. "Rudy" Kohn, Jr USN (Ret.)	
Mr. Maxwell Mulholland	America Superconductor
Dr. William A. Neal , M.D.	West Virginia University
CDR Paul T. Norton, RN (Ret.)	Alstom Power Conversion Ltd
LtGen Keith A. Smith, USMCR (Ret.)	
Dr. Jason Stamp	Sandia National Laboratories
Mr. Howard Stevens	Anteon Corporation
RADM John T. Tozzi, USCG (Ret.)	SYNTEK Technologies Corporation
Mr. Timothy J. Winter	Northrop Grumman Corporation
CDR Stuart Young, RN	Defence Procurement Agency

Study Coordinator

RADM George R. Yount,USN	Naval Sea Systems Command
Mr. David Clayton	Naval Sea Systems Command

Executive Secretary

CAPT Dennis L. Ryan, III, USN (Ret.)	ONR
CAPT Leo G. Dominique, USN (Ret.)	Noesis, Inc.
CDR Joe S. Konicki, USN	Naval Sea Systems Command

***NRAC Member**

Input to Panel

- **40 Technical Briefs**
  - CINCLANTFLT
  - NAVSEA
  - NAVAIR
  - N70
  - ONR
  - SSG
  - USCG
  - UK Royal Navy
  - Newport News
  - Alstom
  - Sandia
- **3 Field Trips**
  - IPS
  - GTS Infinity
  - Brooks AFB
- **33 Papers & Reports**
  - USMC Electric Power Requirements
  - Quadrennial Defense Review Report - 2001

Executive Summary

- Evolving industrial base in electric ships
- **DD(X)**, et al, - Naval electric ship baseline
- Electric Warships unlock propulsion power for electric weapons and advanced sensors
- Flexibility of naval electric power architecture supports evolution to Electric Naval Force
- Central responsibility for Electric Warship technologies essential to achieve warfighting superiority

Outline

- Need - Naval Superiority
- Opportunities - Electric Technologies
- Pathway -
  Electric Ship ➡Electric Warships ➡Electric Naval Force
- Crosscutting Concerns
- Conclusions & Recommendations

Superior Naval Force

Requires

Superior Mission Performance

- "Deeper" Magazines
- Higher Rates Of Fire
- Shorter Weapon Time Of Flight
- Increased Weapons Range
- Improved Long Range Sensing
- Improved Support For Forces Ashore
- Improved Mobility
- Higher Sortie Generation Rates
- More Effective Land Combat Vehicles
- Reduced Cost Per Kill

Superior Naval Force

Also Requires

Superior Survivability

- Longer Range, Higher Resolution Sensing
- More Effective Self Defense
- Improved Speed & Endurance
- Improved Fight Through Capability
- Reduced Signatures
- Reduced Vulnerability
  - Dispersed Power Sources
  - Redundant Power Paths
  - Insensitive Munitions

Affordability

- Reduced Total Ownership Costs
  - Increased Use of COTS
  - Updateable Platforms
- Reduced Workload

Electric Technology Opportunities

Superior Survivability

- ✓ High power microwave applications
- ✓ Dynamic armor
- ✓ Laser weapons
- ✓ Quiet, electrically reconfigurable systems

Superior Mission Performance

- ✓ Electromagnetic guns & launchers
- ✓ High power, high resolution sensors
- ✓ Wireless power transmission

Affordability

- ✓ Flexible, real-time power allocation
- ✓ Automation and commonality
- ✓ Affordable warfighting upgrades

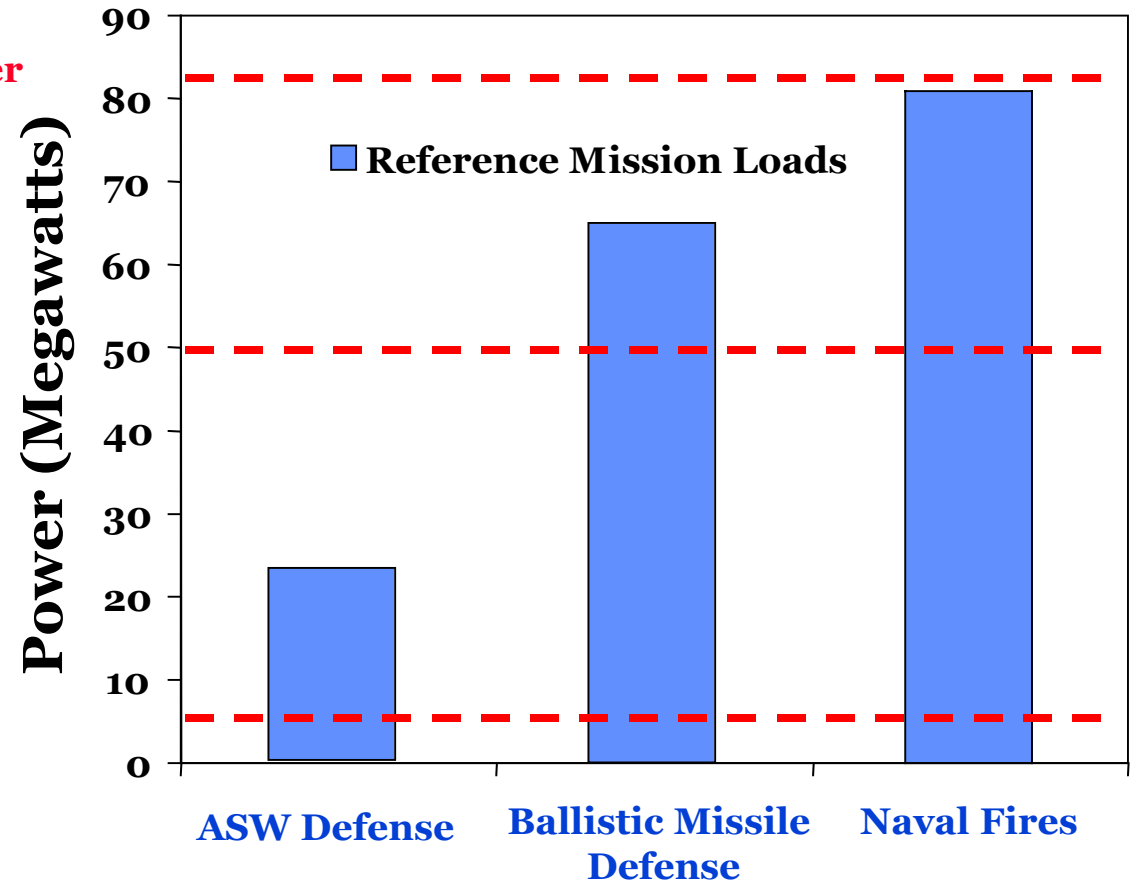
The Problem

The Power Budget

Total Naval Ship Power (typical)

Commercial Electric Ship Power

Naval Ship Service Electric Power



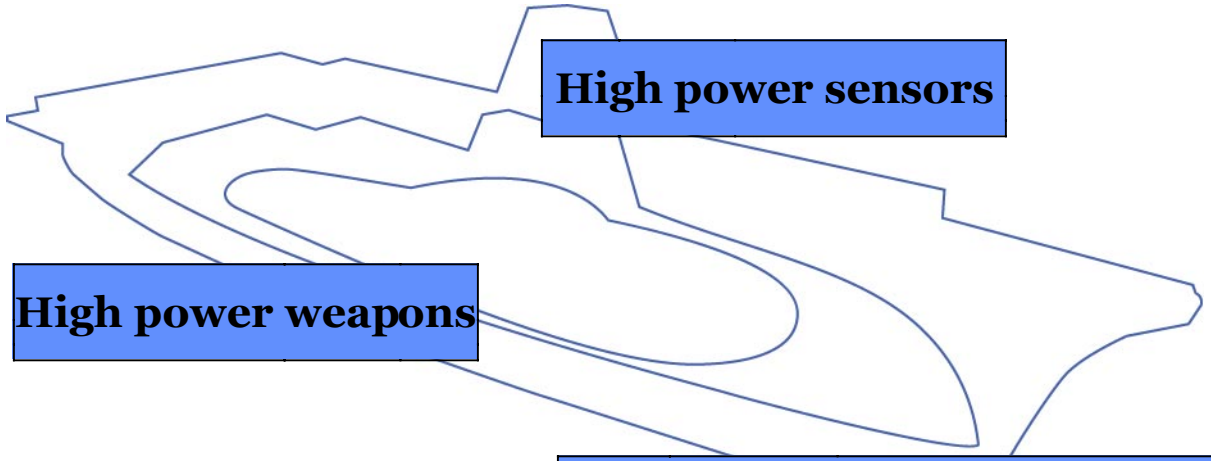
- High Power Active Sonar
- Remote Sensors
- Torpedo Defense

- Laser
- TBMD Radar

- Rail Guns
- High Range/ Resolution Radar

The Solution

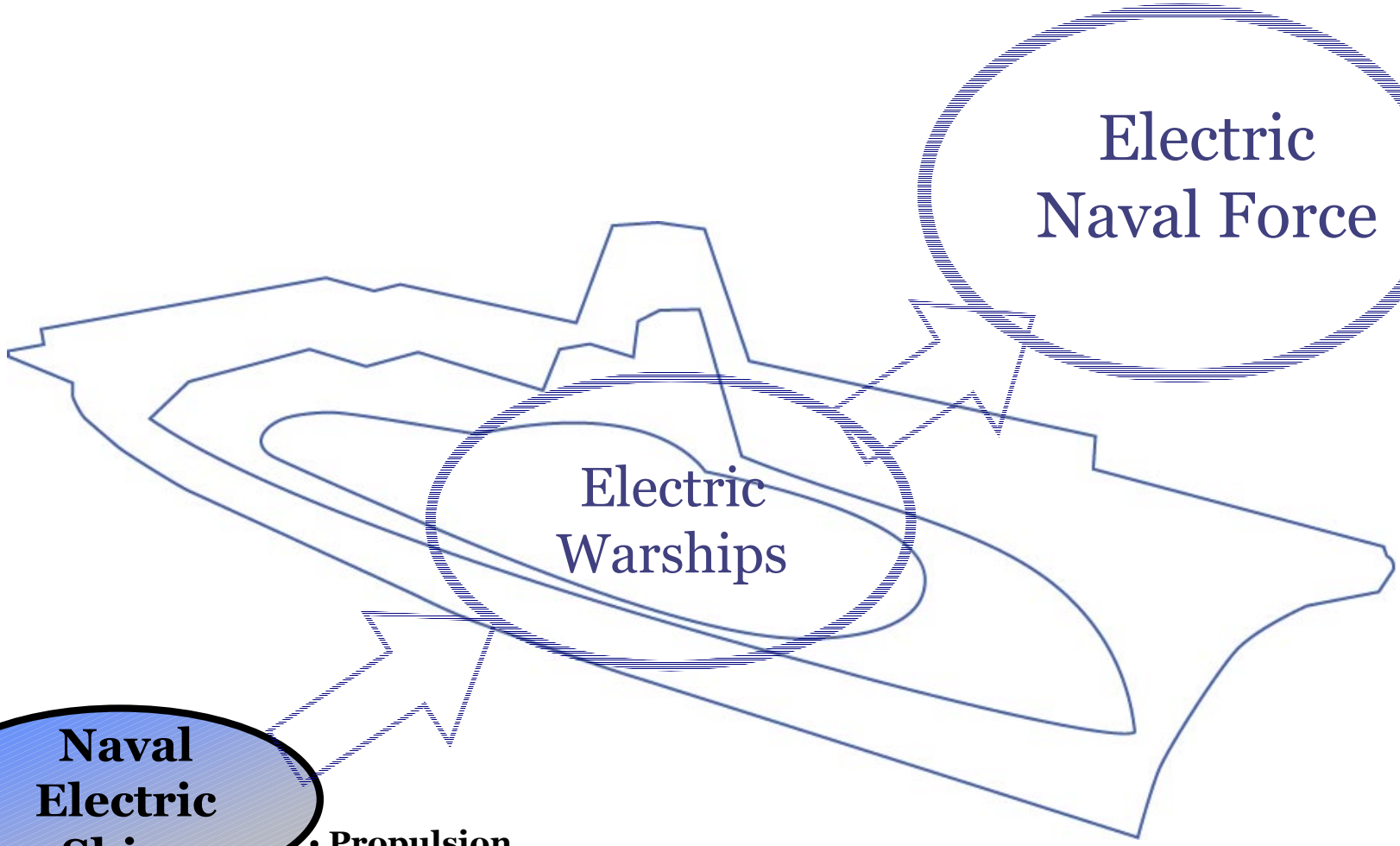
Unlock Propulsion Power to Enable Superior Warfighting Capability



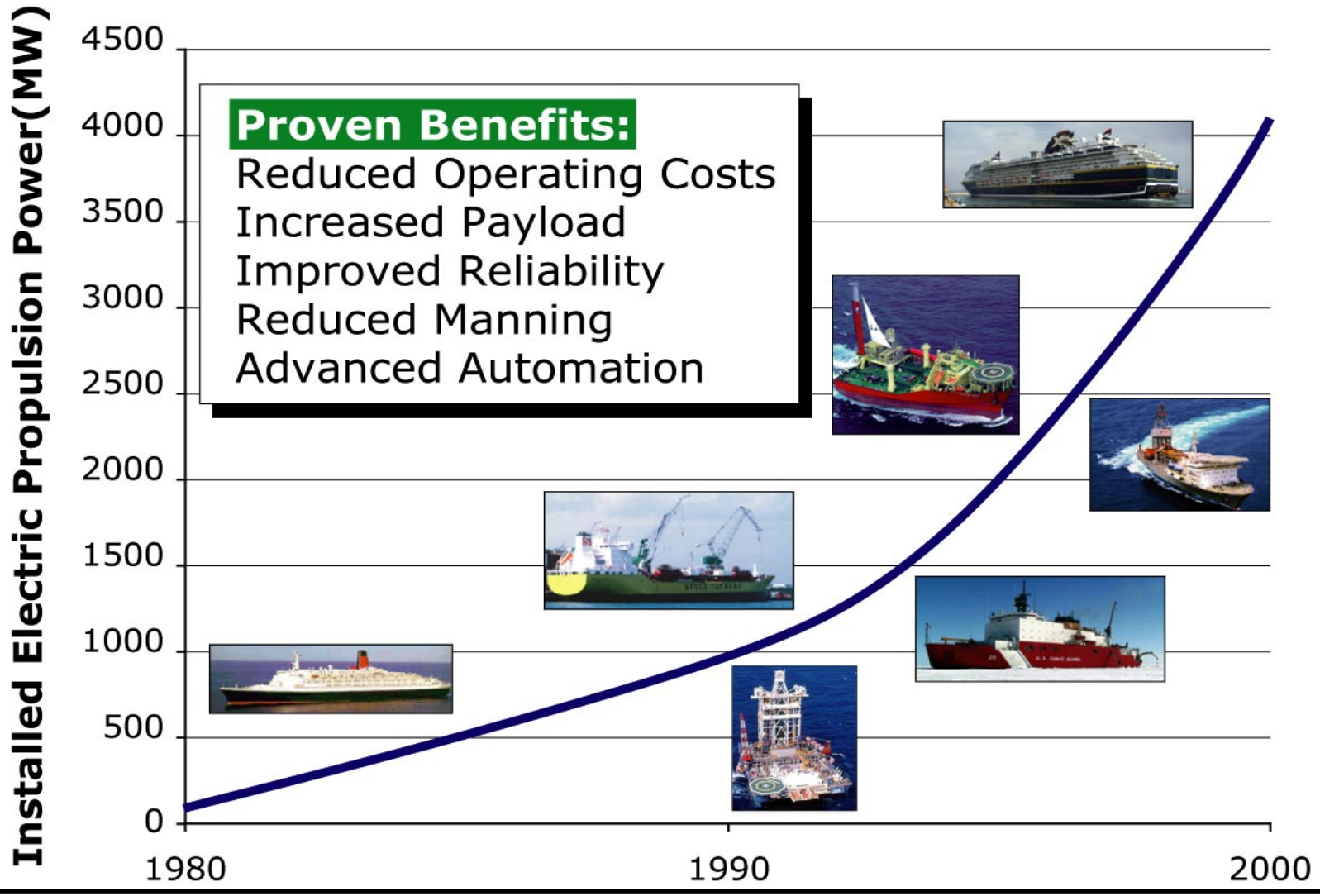
Forces ashore

The Pathway

To an Electric Naval Force



Commercial Electric Ships



Naval Electric Ships

Provide Today's Baseline

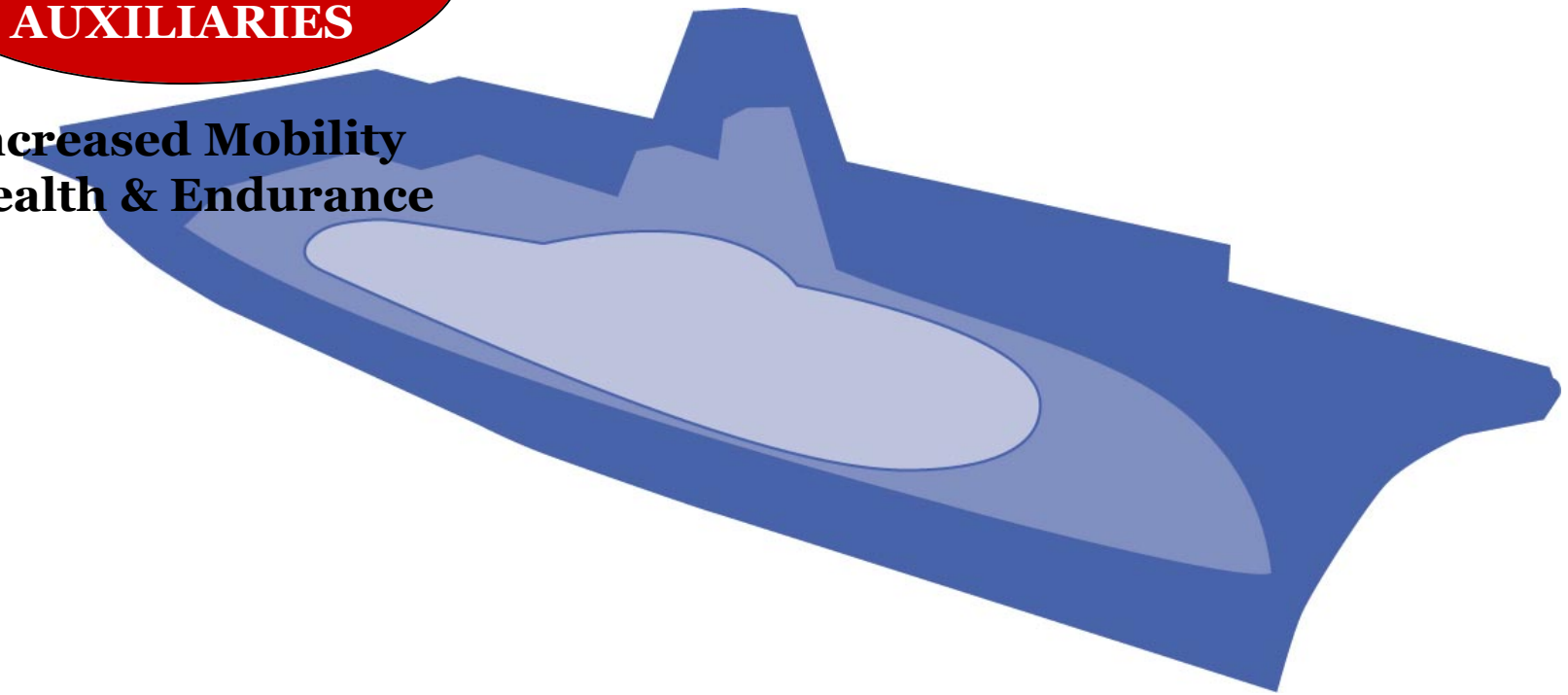
- LHD-8
  - Electric auxiliaries
  - Partially integrated electric power
- DD(X)
  - Naval electric propulsion
  - Integrated power system
- CVNX
  - Large naval turbine generator
  - High voltage, high power distribution system
  - EMALS
  - Electric auxiliaries
- VIRGINIA SSN
  - Power conversion technology

Better Naval Electric Ships

Beyond the Baseline

ELECTRIC PROPULSION & AUXILIARIES

Increased Mobility
Stealth & Endurance



Electric Propulsion & Auxiliaries

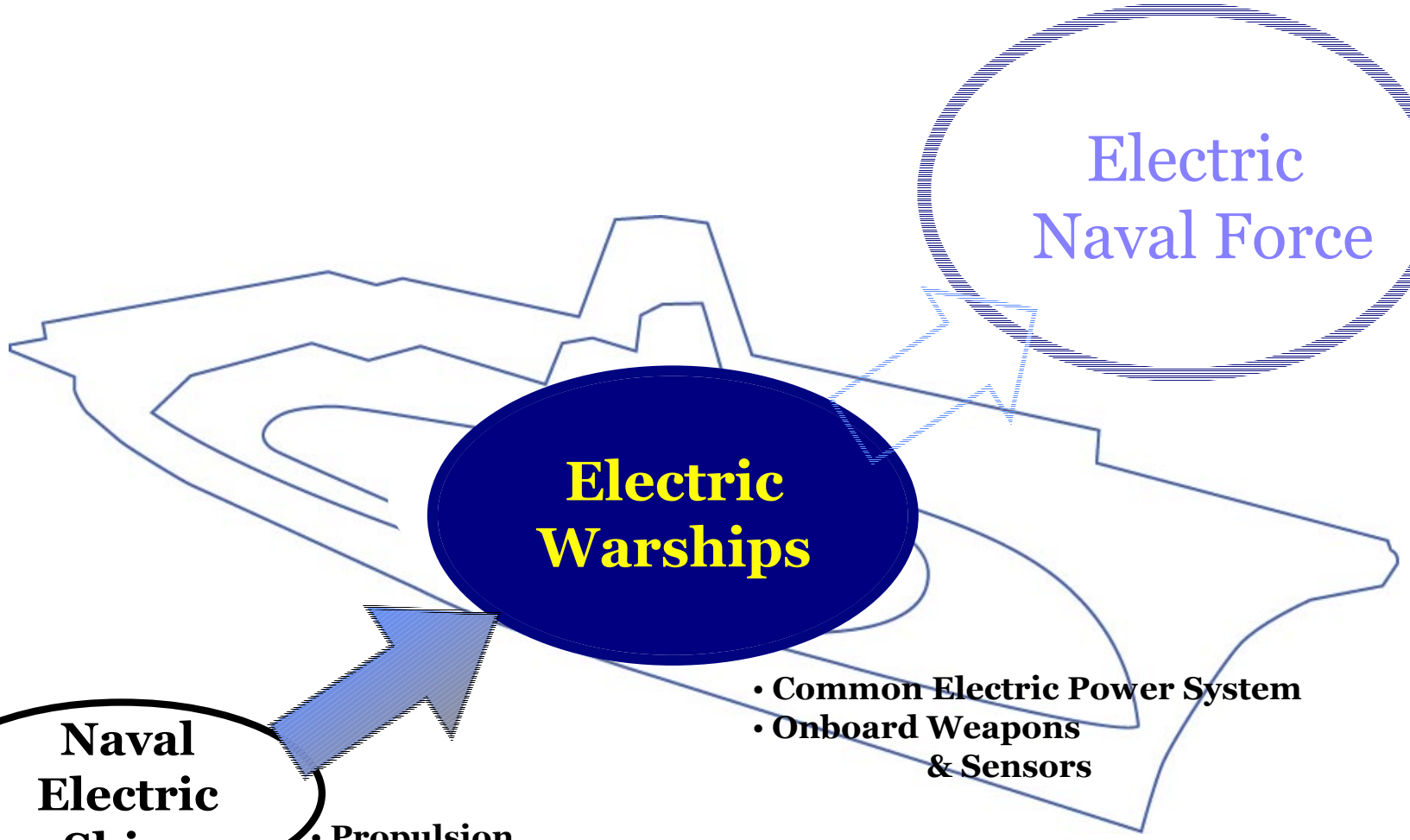
Key Elements

- **Propulsion Motors**
  - Advanced Development - higher power levels, improved power and torque densities, and reduced signatures.
  - S&T - advanced motor concepts, analytical tools, materials, thermal management, and insulation.
- **Propulsion Motor Drives**
  - S&T - thermal management, insulation and shielding which could improve power levels, power density, and signatures
- **Propulsors**
  - Advanced Development - higher power levels, maneuverability, survivability, efficiency and low signatures
  - S&T - advanced propulsor concepts, materials and analytical tools
- **Auxiliaries**
  - Advanced Development - thermal management, intelligent automation, improved load matching and reduced signatures
  - S&T - advanced system concepts, intelligent systems, materials, thermal management concepts, high force actuators

Necessary but not sufficient for electric warships

Electric Warships

Critical Step to an Electric Naval Force



Electric Warships

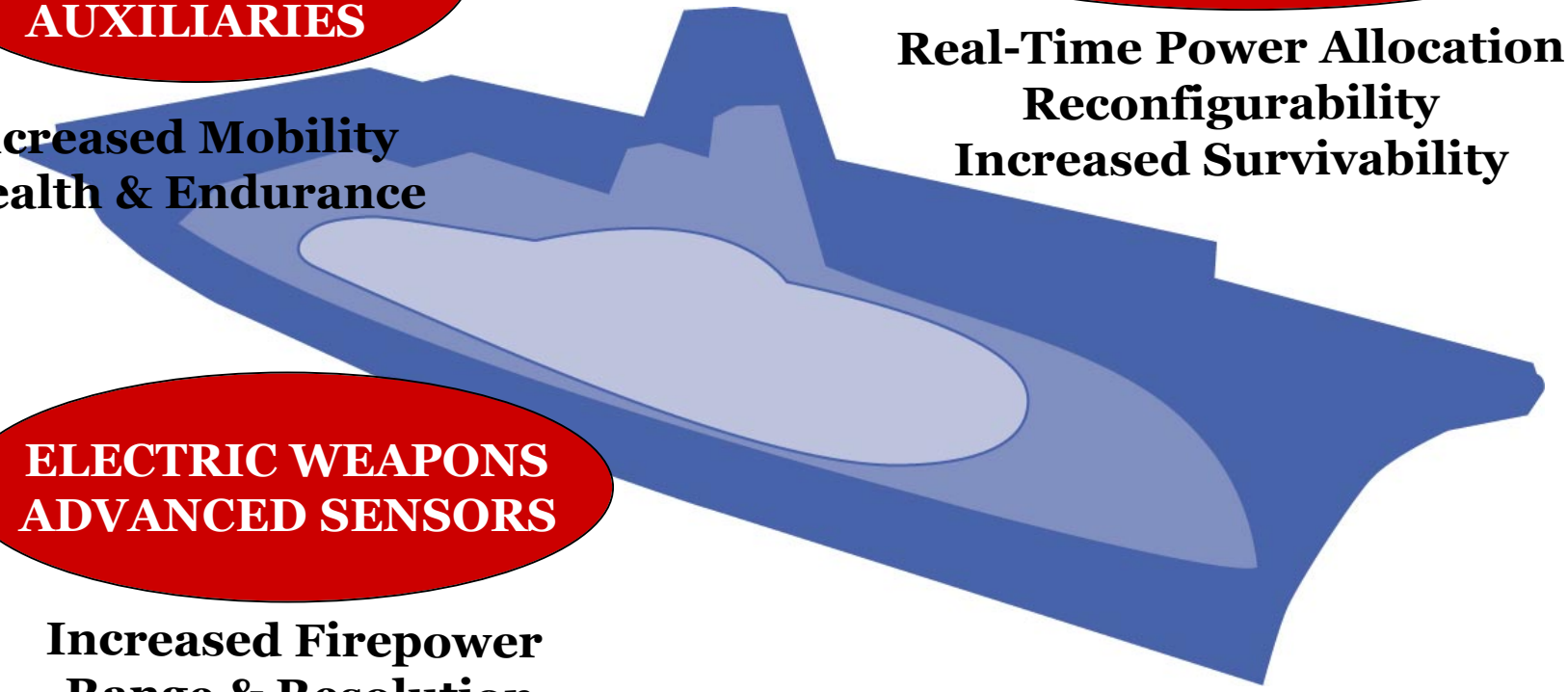
Unlock the Propulsion Power

ELECTRIC PROPULSION & AUXILIARIES

Increased Mobility
Stealth & Endurance

COMMON ELECTRIC POWER SYSTEM

Real-Time Power Allocation
Reconfigurability
Increased Survivability



ELECTRIC WEAPONS ADVANCED SENSORS

Increased Firepower
Range & Resolution

Electric Power System

Key Elements

- **Generation and Energy Storage**
  - Advanced Development - power density, signatures, and fuel efficiency
  - S&T - alternate sources (e.g. fuel cells), pulse power capability for electric weapons and sensors
- **Power Distribution and Conversion**
  - Advanced Development - power quality and fault tolerance
  - S&T - stability and power density
- **Resource Management**
  - Advanced Development - reconfiguration of energy supply and distribution system for fight-through capability
  - S&T - high peak power/pulse power management and stability

Essential for electric warships

Onboard Electric Weapons & Sensors

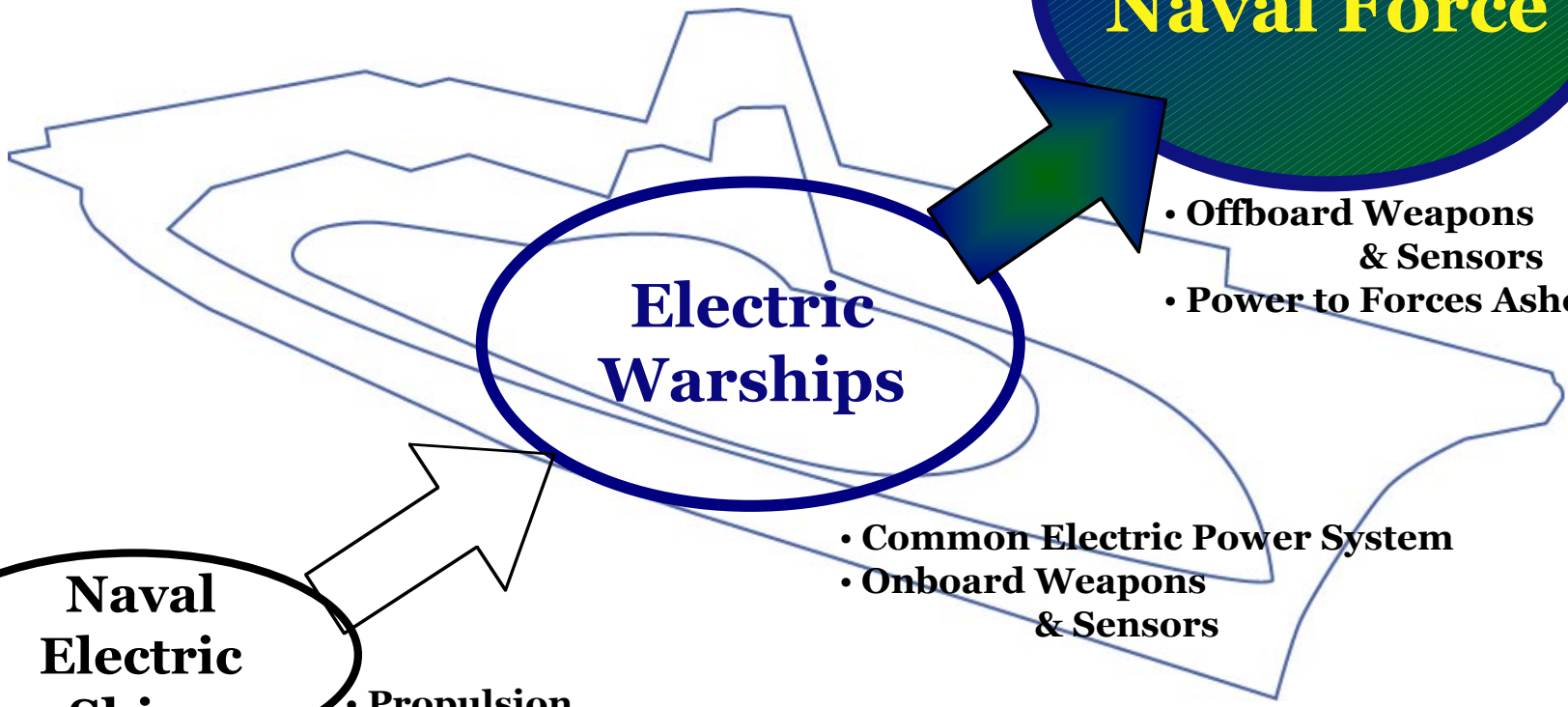
Key Elements

- **Electric Weapons**
  - Advanced Development – HPM Active Denial Capability
  - S&T –HPM Anti-Missile Self Defense, High Power Electric Lasers, EM Gun Systems
- **Sensors**
  - Advanced Development – Increased Radar Range and Resolution
  - S&T – Wide Band Gap Material RF Semiconductors, Thermal Management
- **Launchers**
  - Advanced Development – EMALS & EARS for CVNX
  - S&T – Launchers for Torpedoes, Countermeasures, U-Vehicles/Systems

Justification for electric warships

Electric Naval Force

Warfighting Superiority



Electric Warships

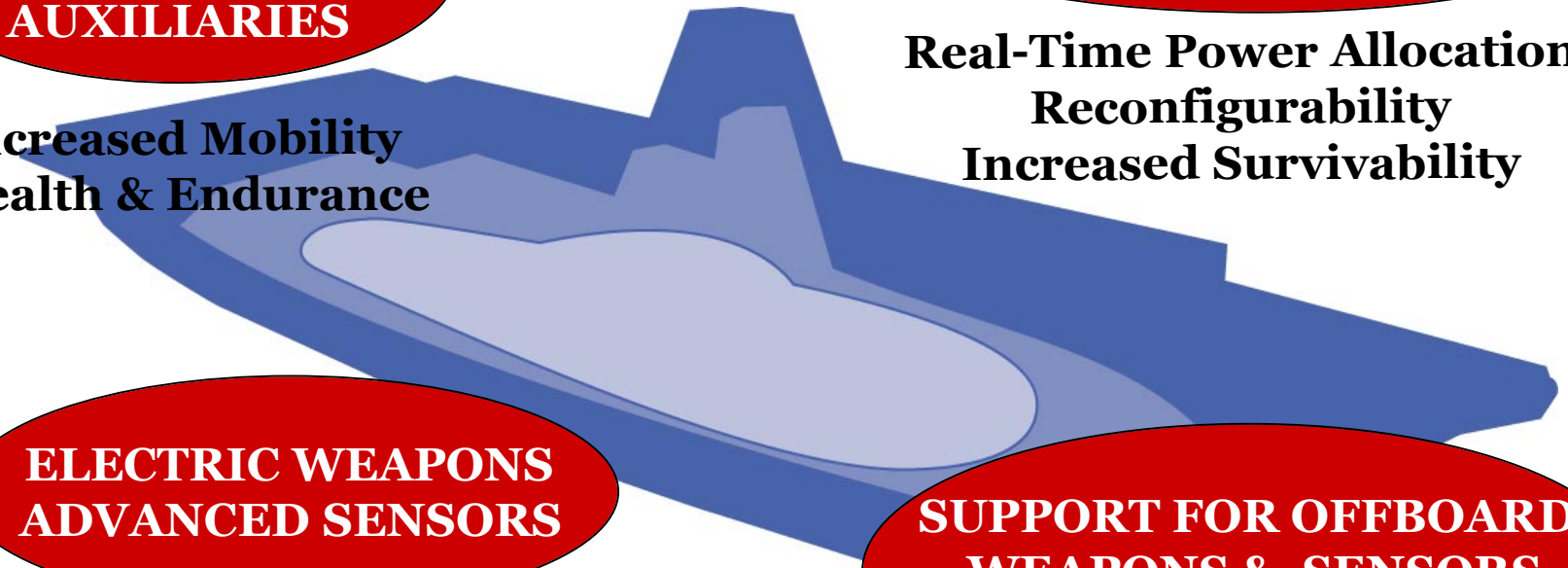
Enable the Electric Naval Force

ELECTRIC PROPULSION & AUXILIARIES

Increased Mobility
Stealth & Endurance

COMMON ELECTRIC POWER SYSTEM

Real-Time Power Allocation
Reconfigurability
Increased Survivability



ELECTRIC WEAPONS ADVANCED SENSORS

Increased Firepower
Range & Resolution

SUPPORT FOR OFFBOARD WEAPONS & SENSORS AND FORCES ASHORE

Increased Reach &
Warfighter Sustainment

Offboard Electric Power

Key Elements

- **Unmanned/Unattended Weapons & Sensors**
  - Advanced Development – Higher Energy & Power Density Systems and Batteries
  - S&T – Fuel Cells, Wireless Power Transmission
- **Individual Marines**
  - Advanced Development – Higher Energy & Power Density Systems and Batteries
  - S&T – Small, Light Weight Fuel Cells
- **Hybrid Electric Combat Vehicle Propulsion & Weapons**
  - Advanced Development – Active Denial High Power Microwave, High Power Density Systems, Hybrid Electric Drives
  - S&T – Weapons Power Systems, Lasers, Anti-Missile High Power Microwave, Wireless Power Transmission

Realization of electric naval force

Electric Power System

Detailed Assessment

	Advanced Development Impact/Risk/Cost	**Technology Demonstration** Impact/Risk/Cost	**Research** Impact/Risk/Cost
Generation Systems	**H / L / M** Turbine Generator	**H / M / H** Advanced Generator **H / M / H** Ship's Service Fuel Cell	**H / H / H** Propulsion Fuel Cell
Energy Storage	**L / L / M** Batteries **L / L / L** Flywheels **L / L / L** Redox	**L / M / M** Super Capacitors **H/M/M** Advanced Batteries	**L / H / H** Super Conducting Magnetic Energy Storage
Pulse Power	**H / L / L** Pulsed Flywheel	**H/ M / M** Compulsators **H / M/M** Pulsed Capacitors (3 J/gm)	**H / H / M** High Action Switch **H/H/M** Pulsed Capacitors (10 J/gm)

Crosscutting Concerns

Electric Warships/Electric Naval Force

- **Systems Engineering**
  - Validated models
  - Configuration control
  - Interface definition
- **Thermal Management**
- **Health/Safety Standards for Low Frequency Magnetic Fields (Draft IEEE 1555 standard)**
- **Military/Industrial/Academic infrastructure**

Conclusions

- **Navy on the path to ELECTRIC SHIPS**
- **ELECTRIC WARSHIPS add flexible real-time power allocation**
- **Electric weapons and advanced sensors provide the technically superior ELECTRIC NAVAL FORCE**

Conclusions (cont'd.)

- **Navy not yet fully committed to ELECTRIC WARSHIPS**
- **Common technology base essential for ELECTRIC NAVAL FORCE**
- **No technology development strategy exists for the ELECTRIC NAVAL FORCE**

Recommendations

- **Establish centralized responsibility for implementing DoN commitment to ELECTRIC WARSHIPS**
- **Develop balanced technology investment strategy for the ELECTRIC NAVAL FORCE**

Electric Naval Force

If Navy Commits Now…

- **Immediate benefits:**
  - Fuel efficiency
  - Endurance
  - Range
  - Crew workload
  - Maintenance
  - Graceful degradation
  - Physical arrangement flexibility
- **Future benefits:**
  - Superior warfighting upgrades

The Alternative

What Happens If We Don't…

Disconnected from Industrial Base

Warfighting Upgrades Unaffordable

~~*Superior*~~ *Naval Force*

"Transformation is not a goal for tomorrow, but an endeavor that must be embraced in earnest today" **Quadrennial Defense Review, Sept. 2001**

Electric Propulsion & Auxiliaries

Detailed Assessment

Element **Critical attributes**	**Advanced Development** Impact/Risk/Cost	**Technology Demonstration** Impact/Risk/Cost	**Research** Impact/Risk/Cost
Propulsion Motors Higher Power Levels Greater Power Density Lower Signatures	**H / M / H** Demonstrated Motor Designs	**H / H / M** Advanced Motor Concepts	**H / L / L** Advanced Motor Technologies (materials, cooling, insulation, etc)
Propulsion Motor Drives Higher Power Levels Greater Power Density Lower Signatures RMA	No investment in new drive architectures warranted at this time - advanced, higher power semiconductors and control circuits in development by industry.		**H / L / M** Advanced Drive Technologies (cooling, insulation, shielding)
Propulsors Higher Power Levels Greater Efficiency Lower Signatures Improved Survivability Enhanced Maneuverability	**M / M / M** Demonstrated Propulsor Designs	**H / M / M** Advanced Propulsor Concepts	**M / L / M** Advanced Propulsor Technologies (materials, analytical tools)

Electric Propulsion & Auxiliaries

Detailed Assessment

Element **Critical attributes**	**Advanced Development** Impact/Risk/Cost	**Technology Demonstration** Impact/Risk/Cost	**Research** Impact/Risk/Cost
Auxiliaries -Elimination of air, hydraulic and steam machinery and actuators -Thermal Management -Automation (damage control, reduced manning) -Efficiency (load matching) -Reduced signatures	**M/M/M** Demonstrated Auxiliary System Designs	**M/M/M** Advanced Auxiliary System Concepts (Concept EDM's)	**M/L/M** Advanced Auxiliary System Technologies (Intelligent Systems, Materials, Thermal Management concepts, high force actuators)

Naval Electric Power

Detailed Assessment

	Advanced Development Impact/Risk/Cost	**Technology Demonstration** Impact/Risk/Cost	**Research** Impact/Risk/Cost
Transmission	**L / L / L** 15kV Shipboard Cable		**M / H / H** Superconducting Cables
Circuit Protection/ Switchgear	**M / L / M** Electromechanical	**M / M / M** Hybrid	**L / H / H** Solid State
Power Conversion/ Conditioning	**M / L / M** Ship Service Conversion	**M / M / M** Advanced Power Converters	**M / H / H** Superconducting Transformers
Power Management/ System Reconfiguration	**H / L / L** Reconfig./Sys. Mgt./Prot. System **H / L / L** Comm./Control Infrastructure **H / L / M** Power Quality	**H / M / M** Large Signal Stability **H / M / L** Active Stabilization	**H / M / L** Predictive Reconfiguration

Onboard Electric Weapons & Sensors

Detailed Assessment

Power for	Advanced Development Impact/Risk/Cost	Technology Demonstration Impact/Risk/Cost	Research Impact/Risk/Cost
EM Launch & Recovery	**H/M/H** EMALS & EARS	**M/M/M** Torpedo, Countermeasure, U-Vehicles/systems Launchers	
EM Guns		**H/M/H** Land Attack/ Support of Forces Ashore/Ship Defense	**H/H/M** Guided Projectiles, Barrel Materials
High Power Radar	**M/M/H** Initial Capability	**H/M/H** Full Capability	
High Power Microwave	**M/M/M** Active Denial	**H/H/H** Anti-Missile	
Laser		**M/M/M** Solid State	**H/H/H** Free Electron

Offboard Electric Power

Detailed Assessment

Power for	Advanced Development Impact/Risk/Cost	Technology Demonstration Impact/Risk/Cost	Research Impact/Risk/Cost
Unmanned/ Unattended Weapons & Sensors	**M/M/M** Application of Advanced Batteries	**M/M/L** Application of Alternate Energy Sources	**H/H/M** Wireless Power Transmission
Individual Marines	**H/M/M** Application of Advanced Batteries	**H/M/M** Application of Alternate Energy Sources	
Hybrid Electric Combat Vehicle Propulsion & Weapons	**H/M/M** Hybrid Power/Propulsion	**M/M/M** Advanced Power/Propulsion Subsystems	**H/M/M** Electric Weapons, Advanced Power/RF Components